Composite Replica Mirrors for Lightweight Space-Based Optics

Stephen Vining & Dr. Patrick Hood
Cornerstone Research Group, Inc.
Dayton, OH 45440
937.320.1877

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ACKNOWLEDGMENT

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OVERVIEW

- Program Introduction
- Phase I Plan
- Phase I Results
- Phase II Plan
- Phase II Early Results
- Summary

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PROGRAM INTRODUCTION

- **Applications: Space-Based Optics**

- **Operational Need: Improve on glass & metal mirrors**
  - **Lighter**
  - **Tougher**
  - **Cheaper**

Images
L: www.fas.org/spp/starwars/program/sbl.htm
R: www.ball.com/aerospace/prod rs bus.html

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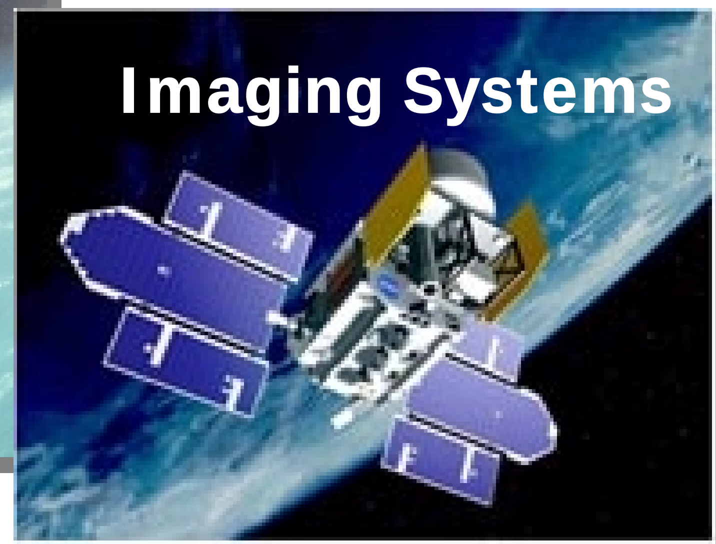
PROGRAM INTRODUCTION

- **Applications: Space-Based Optics**



- **Operational Need: Improve on glass & metal mirrors**
  - **Lighter** → **new material**
  - **Tougher** → **new material**
  - **Cheaper** → **new process**

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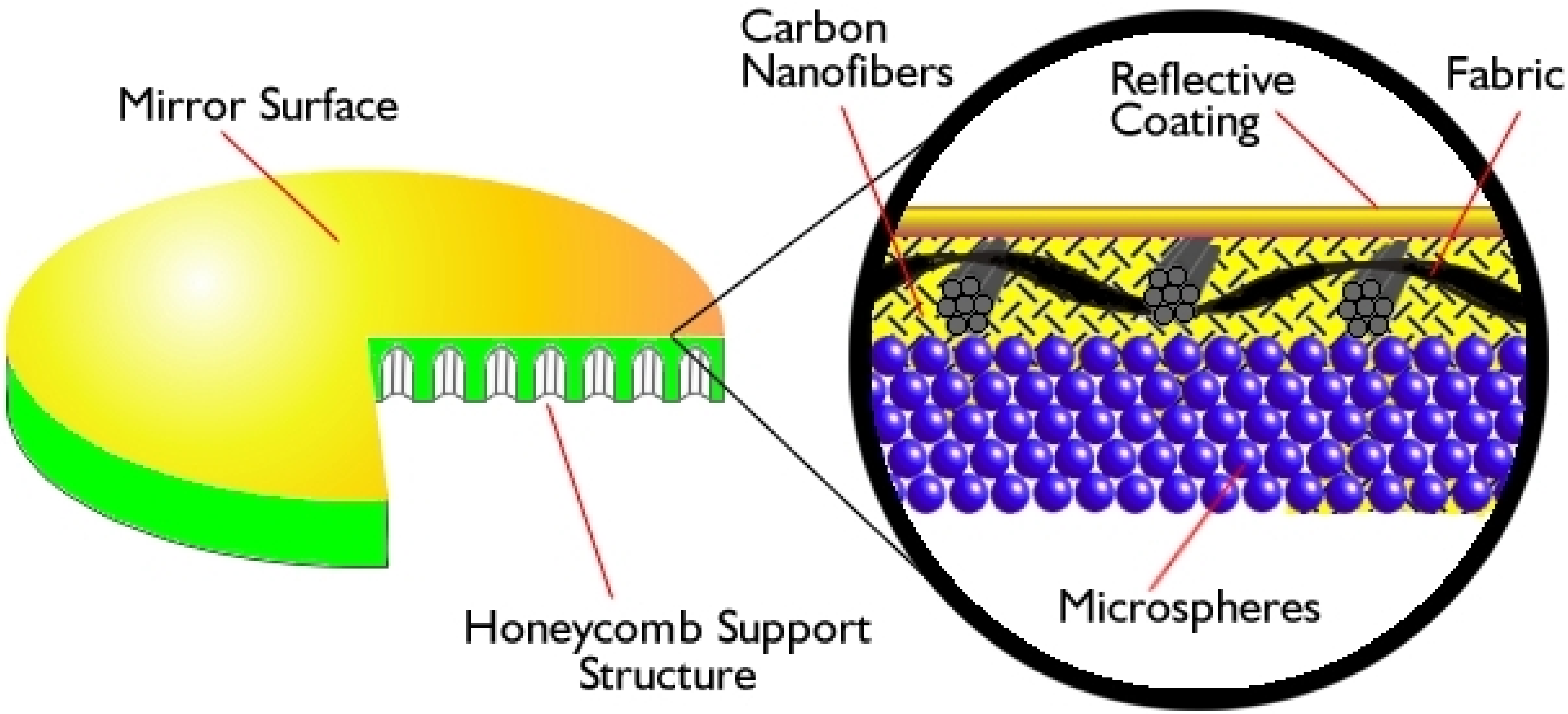
PROGRAM INTRODUCTION:
Material Concept

Multi-Component Composites



PROGRAM INTRODUCTION: Fabrication Concept

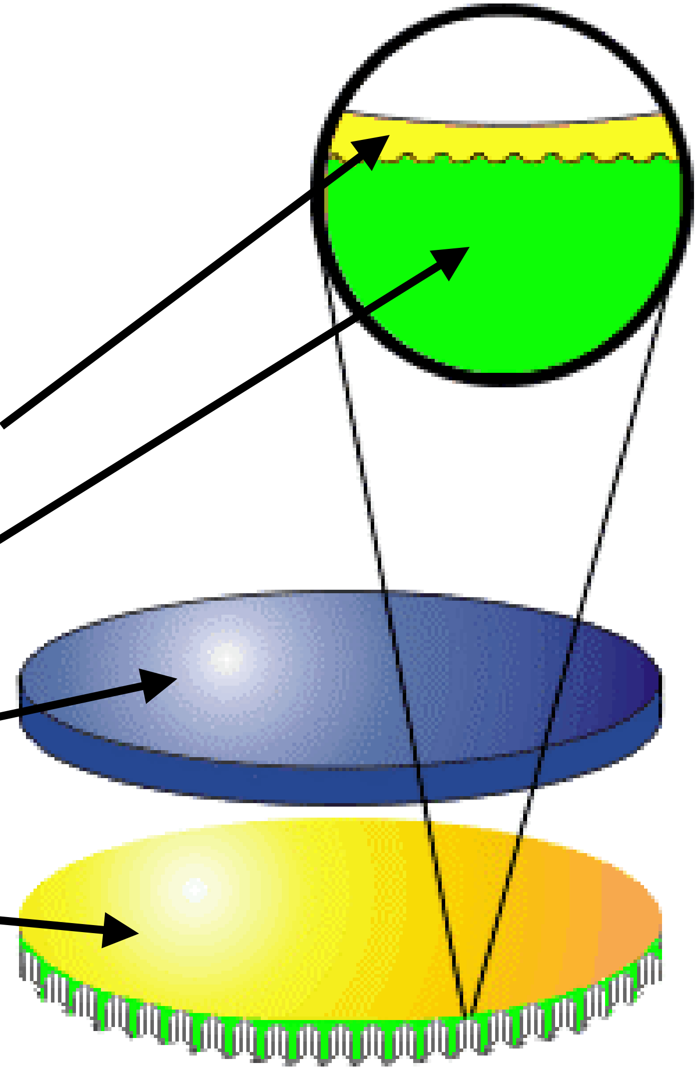
Cast Optical Surface (no grinding or polishing)

Polymer Mirror Surface

Mirror Substrate

Optical Quality Reusable Mold

Released Composite Mirror (final figure & finish)



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PROGRAM INTRODUCTION: Material Design Elements

- Space compatible:
  - Radiation hard (to space ambient)
  - AO resistant (inherent or through practical coating)
  - Resistant to out-gassing in vacuum
- Improvement over glass or metal mirrors:
  - Lower areal density
  - Higher tolerance to thermal excursion (low CTE)
  - Improved strength (toughness & stiffness)
- Compatible with obtaining optical surface

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PHASE I PLAN: Technical Objectives

1. Formulate multi-component composites tailored for space-based mirrors
2. Develop fabrication process
3. Characterize candidate materials
4. Assess candidates' feasibility for space-based mirrors
5. Assess candidates' potential for mirror producibility

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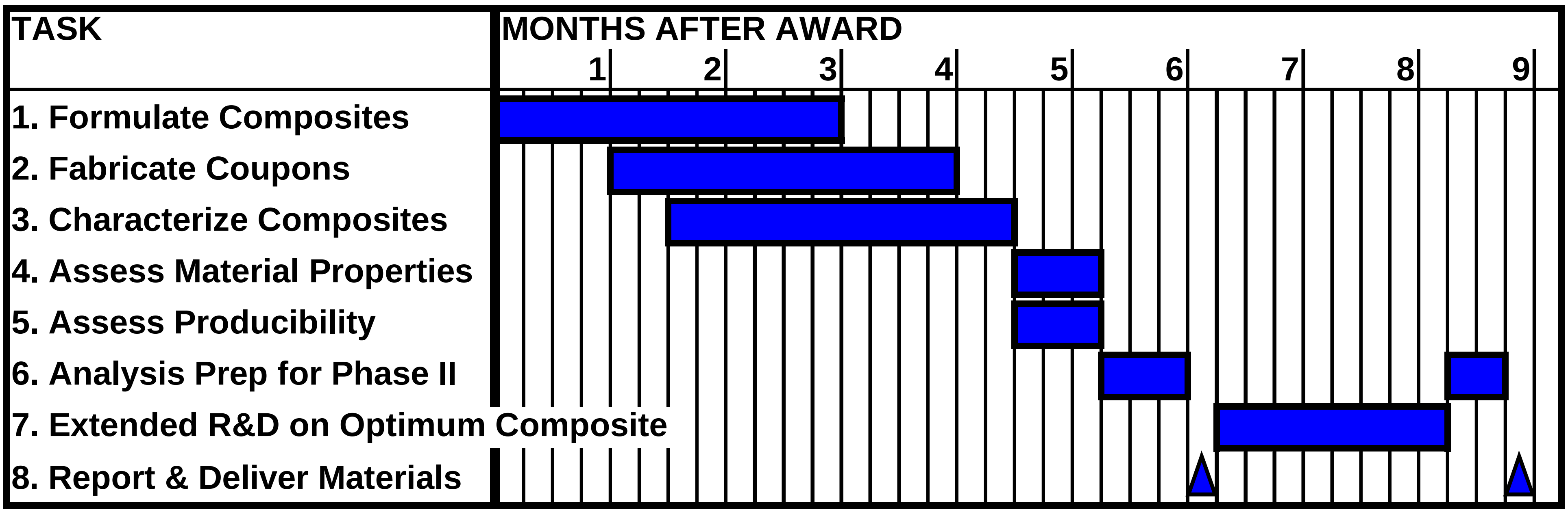
PHASE I PLAN



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PHASE I RESULTS: Inorganic Materials

- Sialyte^{TM} Inorganic "Resin"
  - Inherently space compatible chemistry
  - Lattice structure: high stiffness
  - Low-temperature process : fabrication savings

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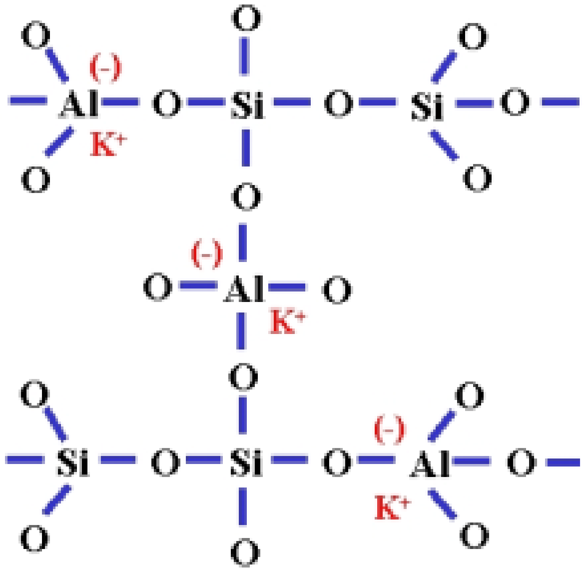
PHASE I RESULTS: Sialyte™ Inorganic "Resin"



poly(sialate-siloxo)

Features

- Castable
- Low temperature cure (60º)
- Low cure shrinkage

Applications

- Propulsion components
- Space-based mirrors

PHASE I RESULTS:
Representative Inorganic Candidates

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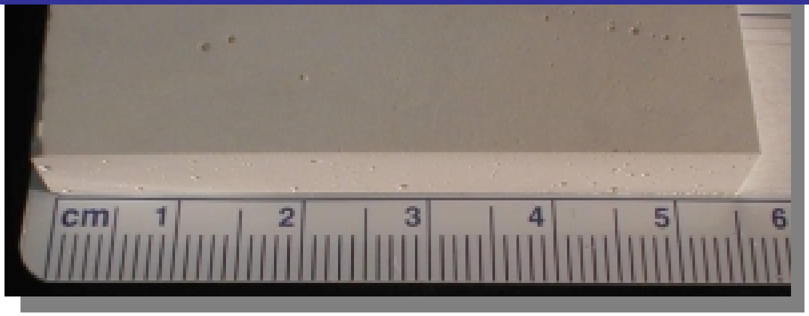
Baseline (Neat) Sialyte™

ZrO_2 Nanoparticle Composite



Glass Syntactic (microspheres)

Carbon Nanofiber-Glass Syntactic Laminate

Carbon Nanofiber Composite

Cyanate Ester Hybrid

PHASE I RESULTS: Sialyte™ Replica Mirror Coupon

Fabrication

- Sialyte™ cast on optical flat
- Gold coating

Finish

- Porous surface
- Roughness:
  - Best local: ~5 nm RMS (neat)
  - Best overall: ~8 nm RMS (ZrO_2 composite)

PHASE I RESULTS: Organic Materials

- **Cyanate Ester Resin**
  - **Demonstrated space compatible chemistry**
  - **Compatible with mature processes demonstrated with epoxy-based materials**
    - **Streamlines composite design**
    - **Streamlines process development**
  - **Formulation experience:**

    Confidence in near term transition

PHASE I RESULTS: Cyanate Ester Organic Resin

High Performance Syntactic Composites

Features

- 0.55 g/cc
- High specific strength
- Superior integrity

Applications

- Strong lightweight spacers
- Insulatory propulsion components
- Missile radomes

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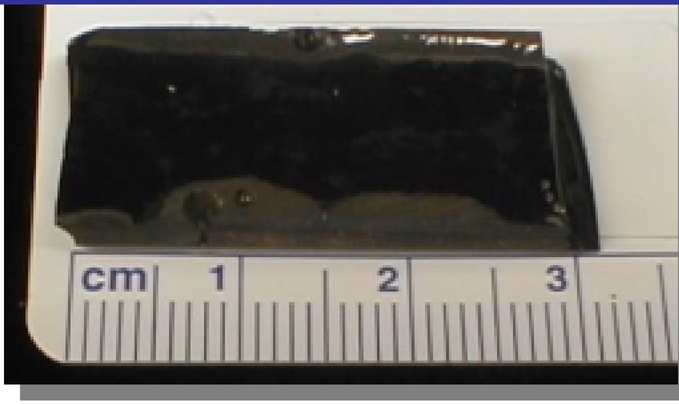
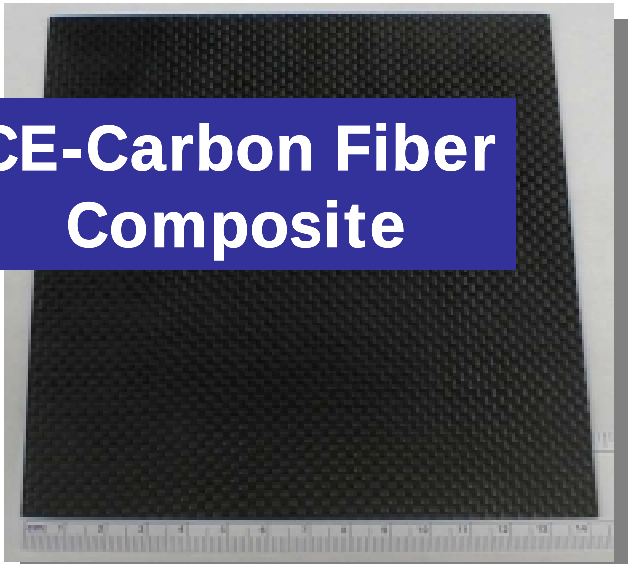
PHASE I RESULTS: Representative Organic Candidates

Cyanate Ester - Glass Syntactic

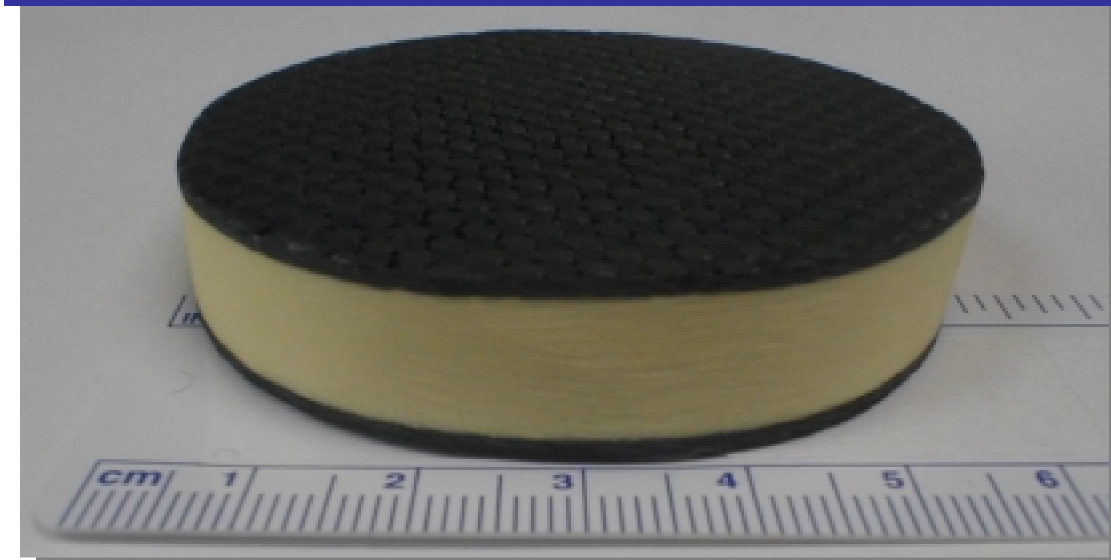
Carbon Nanofiber Reinforcement



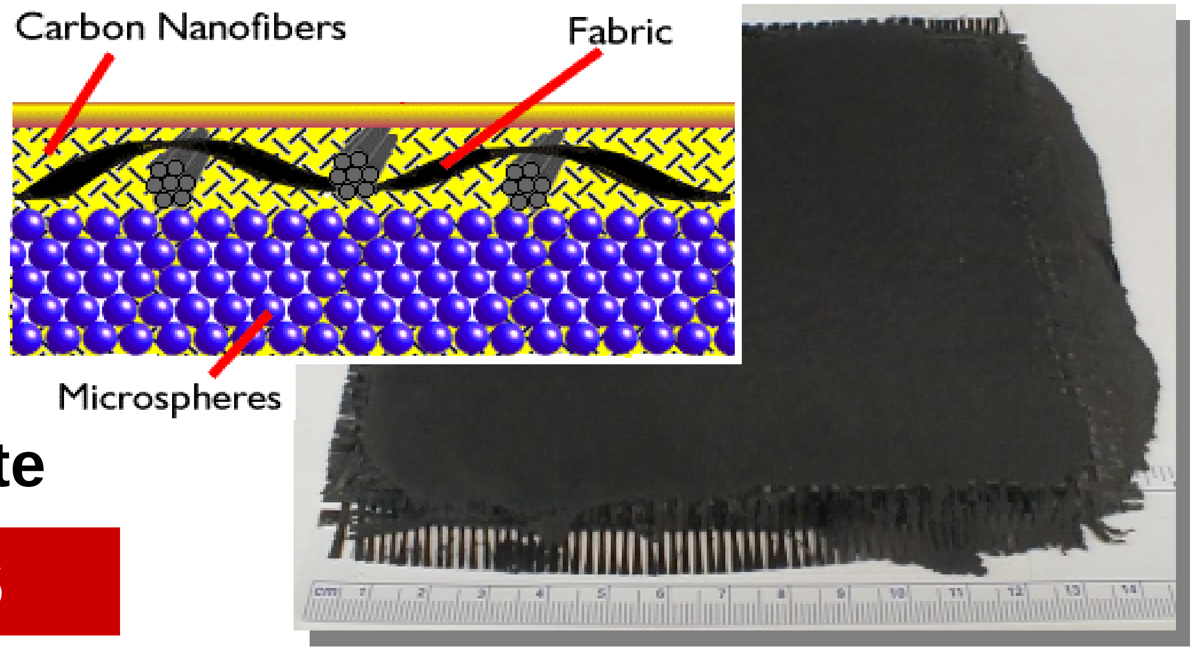
CE-Carbon Fiber Composite



Syntactic-Carbon Fiber Laminate



SUPPORTING IR&D RESULTS: Epon - Glass Syntactic - Carbon Nanofiber & Carbon Fabric Laminate



OBJECTIVE

- Improve strength
- Improve stiffness
- Demonstrate multi-component composite

IR&D RESULTS

Form

- Indicates high potential for strong, stiff support structure integrated with reflective surface

Fabrication

- Multi-component composite feasible
- Requires development in Cyanate Ester

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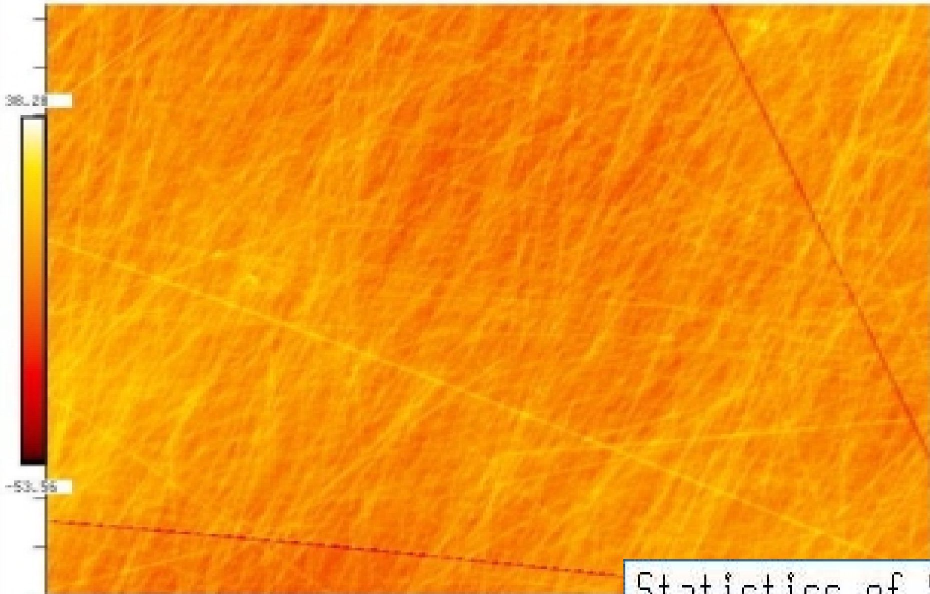
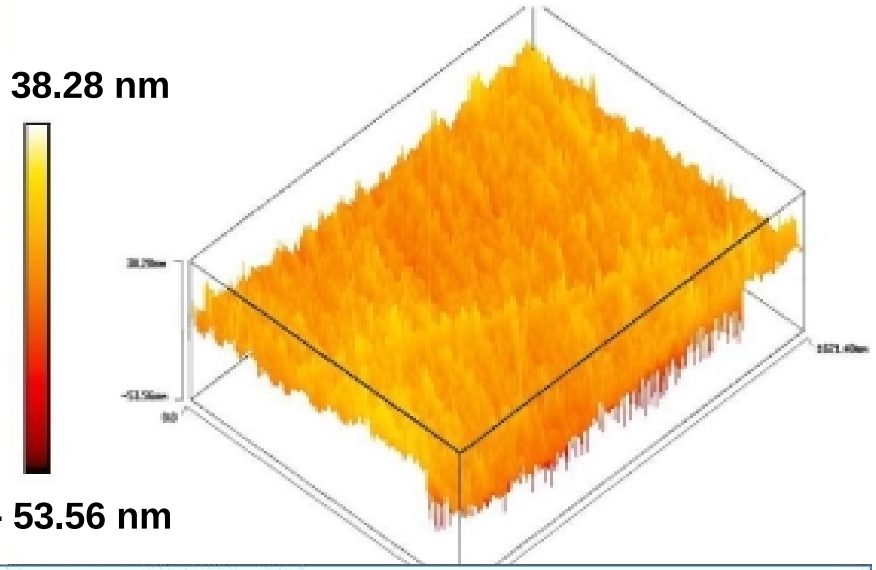
PHASE I RESULTS: Cyanate Ester Surface Finish

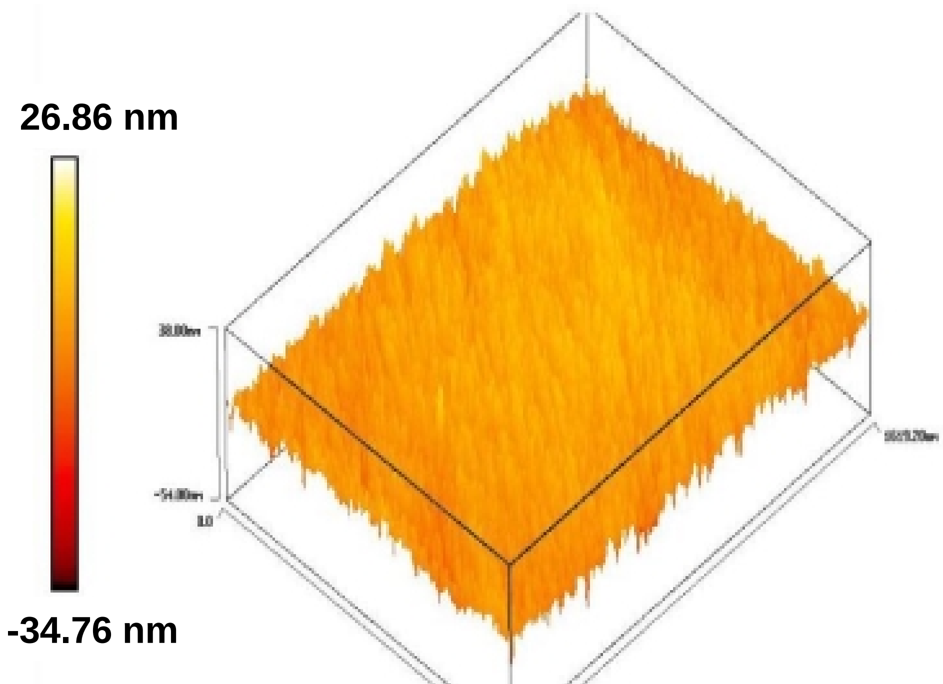




Statistics of Surface: GK40-1A					
Rp:	38.28nm	Rq:	6.09nm	Area:	1621.40x1235.00um
Rv:	-53.56nm	Ra:	4.74nm	Mag :	5.0
PV:	91.84nm	Rsk:	0.05	DATE:	06-14-2002
PT:	350071	Rku:	4.45	TIME:	10:03:38
Terms Subtracted:		Tilt			

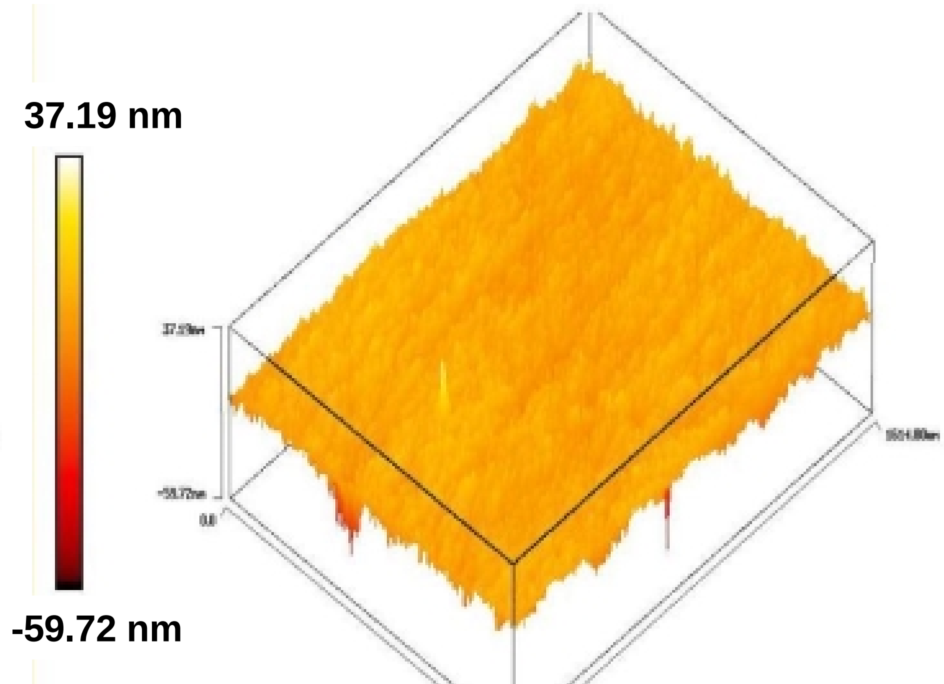
Surface Roughness: 6.09 nm RMS

PHASE I RESULTS: Mold Finish



Statistics of Surface:		PUCK1-A		
Rp: 26.86nm	Rq:	5.41nm	Area: 1619.20x1229.80um	
Rv: -34.76nm	Ra:	4.30nm	Mag : 5.0	
PV: 61.62nm	Rsk:	-0.19	DATE: 06-13-2002	
PT: 348127	Rku:	3.16	TIME: 09:29:50	
Terms Subtracted:	Tilt			

Roughness Before Casting: 5.41 nm RMS



Statistics of Surface:		PUCK1-B		
Rp: 37.19nm	Rq:	4.61nm	Area: 1614.80x1229.80um	
Rv: -59.72nm	Ra:	3.59nm	Mag : 5.0	
PV: 96.91nm	Rsk:	-0.65	DATE: 06-14-2002	
PT: 347182	Rku:	5.65	TIME: 11:56:13	
Terms Subtracted:	Tilt			

Roughness After Casting: 4.61 nm RMS

PHASE I RESULTS: Cyanate Ester - Glass Syntactic Mirror

OBJECTIVE

Demonstrate feasibility of replication approach

RESULTS

Form

Slight curvature
(due to cure shrinkage)

Finish

- Good mold replication
- Good reflective coating

Fabrication

- Good mold release
- Process development needed to improve figure replication
- Initial feasibility established

PHASE I RESULTS:
Cyanate Ester - Syntactic Mirror

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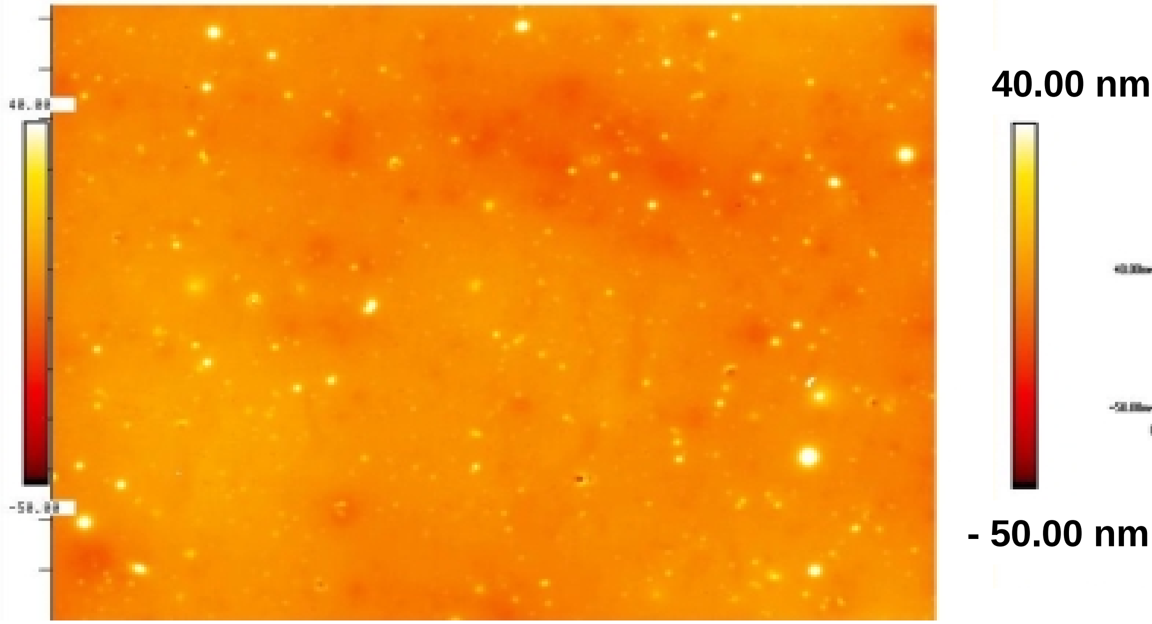

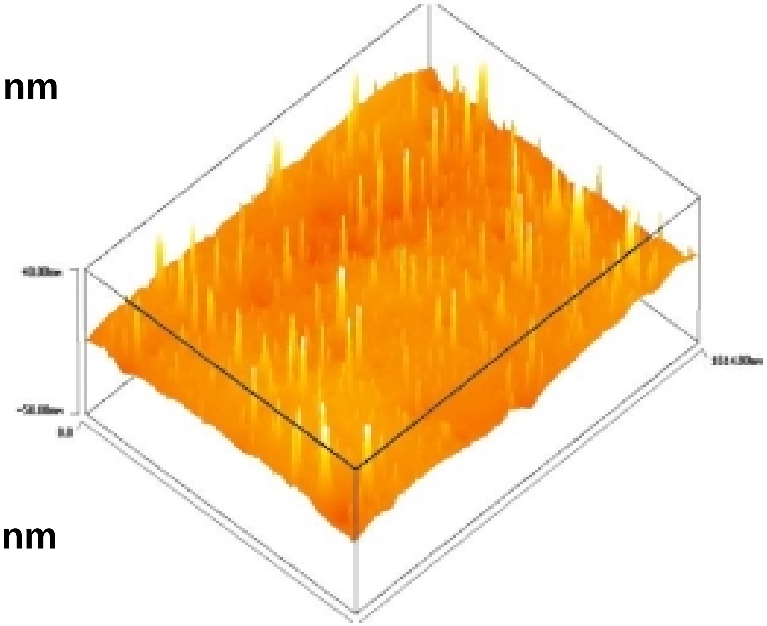

Statistics of Surface:	GK84-B				
Rp:	166.37nm	Rq:	5.15nm	Area:	1614.80x1229.80um
Rv:	-32.51nm	Ra:	3.29nm	Mag :	5.0
PV:	198.88nm	Rsk:	5.13	DATE:	09-05-2002
PT:	347168	Rku:	91.18	TIME:	15:18:39
Terms Subtracted:		Tilt			

Surface Roughness:
5.15 nm RMS

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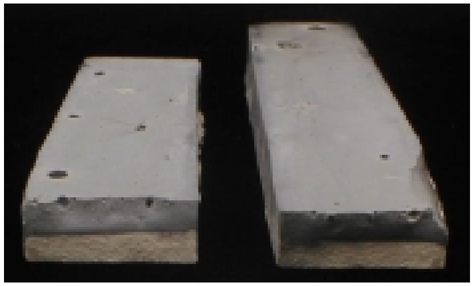
PHASE I RESULTS: Conclusions

- **Sialyte^{TM} Inorganic Composites**
  - Multi-component composites feasible
  - Attributes appear promising for space mirrors
  - Need further development to reach transition



- **Cyanate Ester Organic Composites**
  - Multi-component composites feasible
  - Attributes demonstrated for replica mirrors for space-based optics
  - Ready for transition demonstration

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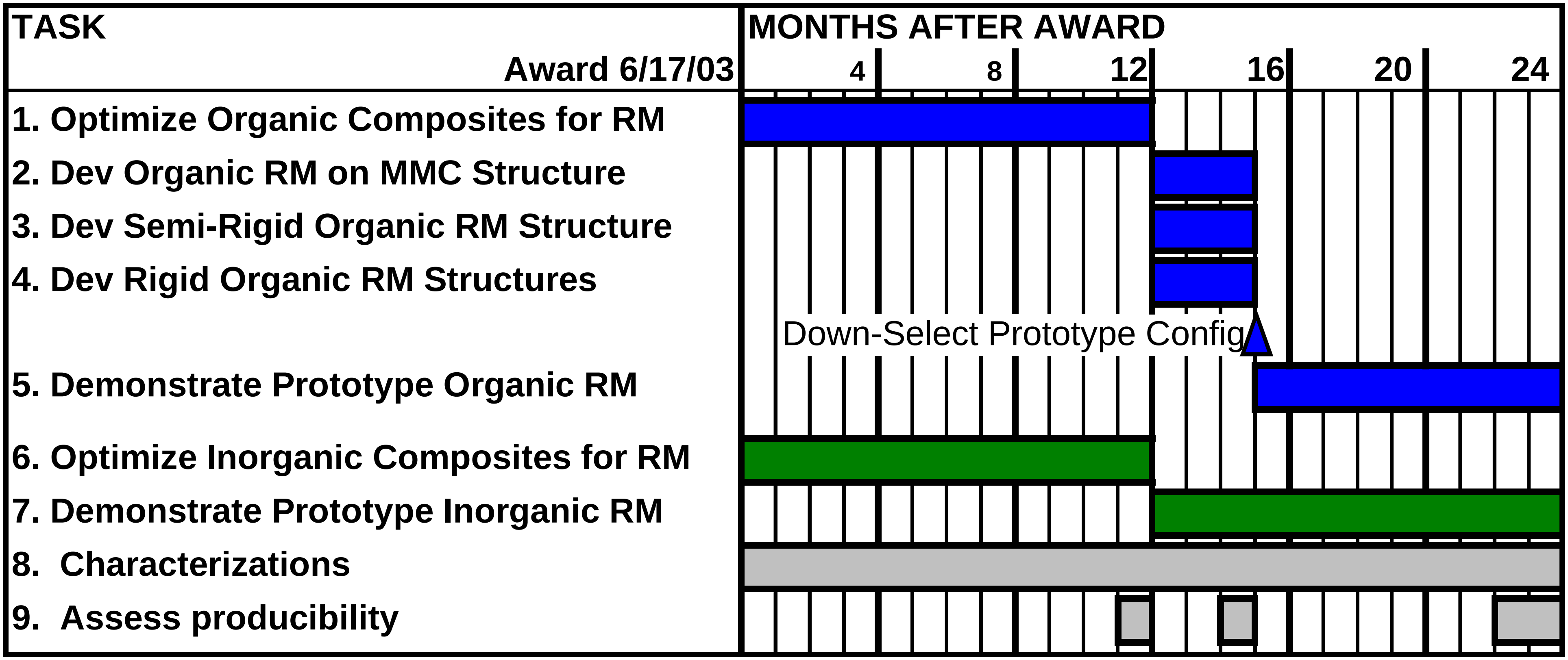
PHASE II PLAN



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PHASE II EARLY RESULTS: Inorganic Materials

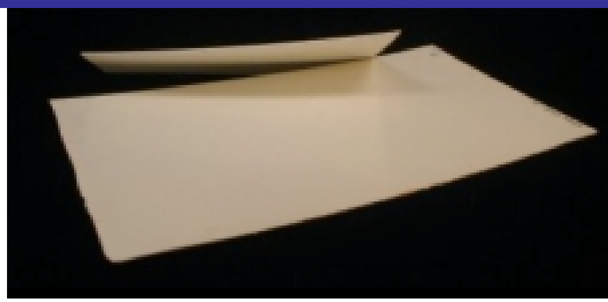
Scaling Up Processes & Optimizing Composites

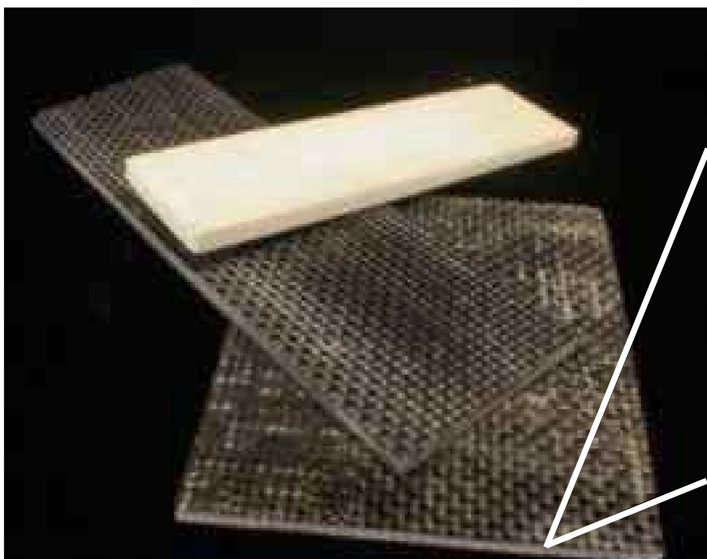
Sialyte™ - Glass Fiber Composite

PHASE II EARLY RESULTS:
Organic Materials

Scaling Up Processes & Optimizing Composites

Cyanate Ester - Glass Syntactic: Thin Sheet (~0.8 mm)





~4.0 mm

Syntactic-Carbon Fiber "Micro-Laminates"

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EXECUTIVE SUMMARY

Composite Replica Mirrors for Lightweight Space Optics

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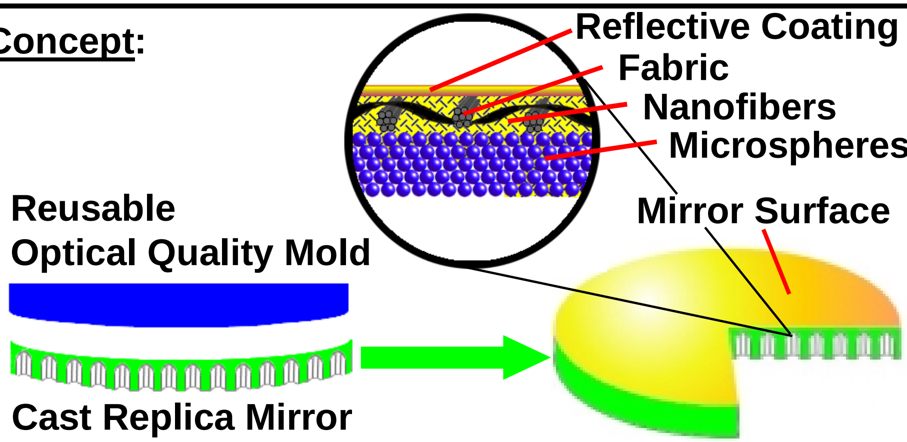
SBIR 2002.1 Topic AF02-129
Phase II Proposal F2-1119
Contract F33615-03-C-5013

Concept:



Operational Benefits:
- Reduced mirror areal density
- Tougher & stronger mirror material
- Reduced mirror fabrication cost & time

AF Application: Space-based imaging systems

Commercial Applications:
- Commercial imaging systems (e.g., LANDSAT)
- Consumer telescopes

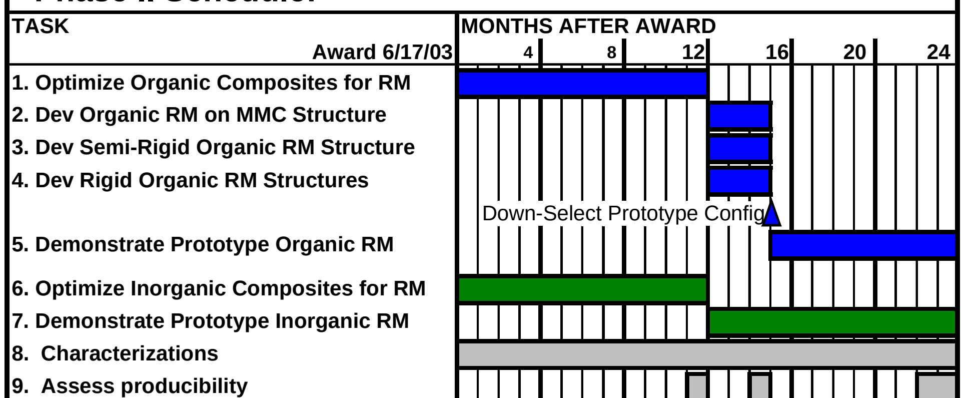
Proposed Approach:

- **Phase I: Create Novel Multi-Component Composite**
  - -- Feasible composites -- demonstrated
  - -- Feasible fabrication processes -- demonstrated

- **Phase II: Demonstrate Replica Mirror (RM)**
  - -- Develop mature composite materials
    - --- Organic: Cyanate ester matrix
    - --- Inorganic: Polysialate or calcium-based matrix
  - -- Develop mature replica fabrication processes
  - -- Develop practical RM design methodology
  - -- Demonstrate operationally relevant prototype mirror

- **Phase III: Commercialization in Consumer Market**

Phase II Schedule:



Deliverables:
- Phase I: Feasible materials & processes -- delivered
- Phase II: -- Mature materials & fabrication processes
  -- Prototype Composite Replica Mirror

Contact: S Vining (937) 320-1877 viningsd@crgrp.net